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# Mechanically-Stimulated Luminescence in Coloured Alkali Halide Crystals

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**ABSTRACT**

When plastic deformation in coloured alkali halide crystals is caused by the movement of dislocations then the electrons are transferred from the f-centres to the dislocation band. Subsequently the moving dislocations transport the captured electrons to the holes at the defect centres whereby the luminescence is produced during the radiative electron-hole recombination. Initially the mechanoluminescence (ML) intensity in coloured alkali halide crystals should increase with time and it should attains a saturation value and finally the ML intensity should decay exponentially. The temperature dependence ML intensity is also explained. It is found that there is a good agreement between theoretical and experimental results.

**Keywords**: Mechanoluminescence, Deformation and Coloured alkali halide crystals.

## INTRODUCTION

Cold emission of light is known as luminescence. Luminescence is the non equilibrium phenomenon of excess emission over and above the thermal emission of body, in which emission has duration considerably exceeding the period of light oscillation. Luminescence induced during mechanical deformation of solids is known as Mechanoluminescence (ML). It can be excited by rubbing, grinding, cutting, cleaving, shaking, scratching, compressing or crushing of solids. ML can also be excited by thermal shocks caused by drastic cooling or heating of materials or by the shock waves produced during exposure of samples to powerful laser pulses. ML also appears during the deformation caused by the phase transition or growth of certain crystals as well as during separation of two dissimilar materials in contact. The phenomenon of ML has also been called by many other names, such as trennugslicht (German word tunnng means seperation) triboluminescence (Greek word triben means to rub),

piezoluminescence, deformation luminescence and stress activated luminescence. A large number of organic and inorganic crystals, amorphous solids exhibit ML[1-4]. It is known that colouerd alkali halide crystals exhibit intense ML during their plastic deformation[5-7]. The present paper reports the ML in coloured alkali halide crystals.

**THEORY**

From the comparison of ML spectra with the spectra of other types of luminescence in X or $\gamma$-irradiated pure alkali halide ctrystals, it has been proved that the ML arises due to the recombination of electrons from F-centres with the hole in $v_2$ cenetres[8,9]. This is confirmed by the fact that pure additively colourd alkali halide crystals do not show ML during their plastic deformation due to the absence of holes. Subsequently, the ML process can be described by the following equations:

$$F + D \rightarrow e_d + [-]$$
$$V_2\left(= X^- + X^- + X^\circ\right) + e_d \rightarrow V_2^-\left(= 3X^-\right) + D + h\upsilon$$

where F and D represent F-centre and dislocation, respectively, $e_d$ is the dislocation electron i.e. the electron captured by dislocation, [-] is the negative ion vacancy, $X^-$ is the halogen ion, is $X^\circ$ self-trapped and $V_2^-$ is the $V_2$ centre with captured electron.

In X or $\gamma$-irradiated impurity doped alkali halide crystals, some of the holes may be in impurities and their recombination with the dislocation electrons may induce the impurity emissions[10].

If $n_F$ is the number of F-centres in unit volume, then the rate of generation of electron in the dislocation band is given by

$$g = \frac{\dot{\varepsilon}}{b} p_F r_F n_F \tag{1}$$

The rate equation for the change in number of electron in the dislocation band as

$$\frac{d(\Delta n_d)}{dt} = g - \sigma_1 N_1 v_d \Delta n_d - \sigma_2 N_2 v_d \Delta n_d - \sigma_3 N_3 v_d \Delta n_d \tag{2}$$

where $\sigma_1$, $\sigma_2$ and $\sigma_3$ are the capture cross-sections of the recombination centers, deep traps and negative ion vacancies, respectively.

If $\eta$ is the probability of radiative recombination of electrons with hole containing centers, then the ML intensity may be written as

$$I = \frac{\eta \sigma_1 N_1 P_F r_F n_F \dot{\varepsilon} V}{\left(\sigma_1 N_1 + \sigma_2 N_2 + \sigma_3 N_3\right) b}\left[1 - e^{-t/\tau_d}\right] \tag{3}$$

where,

$$\tau_d = \frac{1}{\left(\sigma_1 N_1 + \sigma_2 N_2 + \sigma_3 N_3\right) v_d} \tag{4}$$

above equation shows that for a given strain rate, the ML intensity increases with time. Then the saturation of ML intensity $I_s$ is given by

$$I_s = \frac{\eta P_F n_F r_F v \dot{\varepsilon}}{b} \tag{5}$$

The above equation shows that for a given strain rate, $I_s$ should increase linearly with the density of F-centres in the crystals.

When the crosshead of the deforming machine is stoped then the ML intensity should decay with two kinetics, one related to stress relaxation of the crystals and other related to the diffusion of interstitial atoms towards the dislocation[ $D/\ell^2$ ] or the probability of electron- hole recombination due to the movement of electrons along the dislocation. In the above two cases, the decay of ML intensity if ($t-t_c$) is less may be given by

$$I = I_o\, e^{-\alpha(t-t_c)} \qquad (6)$$

where $$Io = \frac{\eta\sigma_1 N_1 v_{do}\, P_F\; r_F\; N_d}{\sigma_1 N_1 + \sigma_2 N_2 + \sigma_3 N_3} \qquad (7)$$

and if ($t-t_c$) is large

$$I' = I'_o e^{-\beta(t-t'_c)} \qquad (8)$$

where $\beta = \left(\sigma_1 N_1 v_s + \frac{D}{\ell^2}\right)$ and

$v_d = v_{do}\exp[-\alpha(t-t_c)]$

The temperature dependence ML intensity is

$$I_s = \frac{\eta n_F r_F V \dot{\varepsilon} P_{FO}}{\sigma_1 N_1 + \sigma_2 N_2 + \sigma_3 N_3} e^{(-E_a/KT)} \qquad (9)$$

where $P_{FO} = \alpha_1^o / \alpha_2$

The above equation shows that for fixed values of $n_F$ and $\dot{\varepsilon}$, the temperature dependence of $I_s$ should follow Arrhenius plot with activation energy $E_a$.

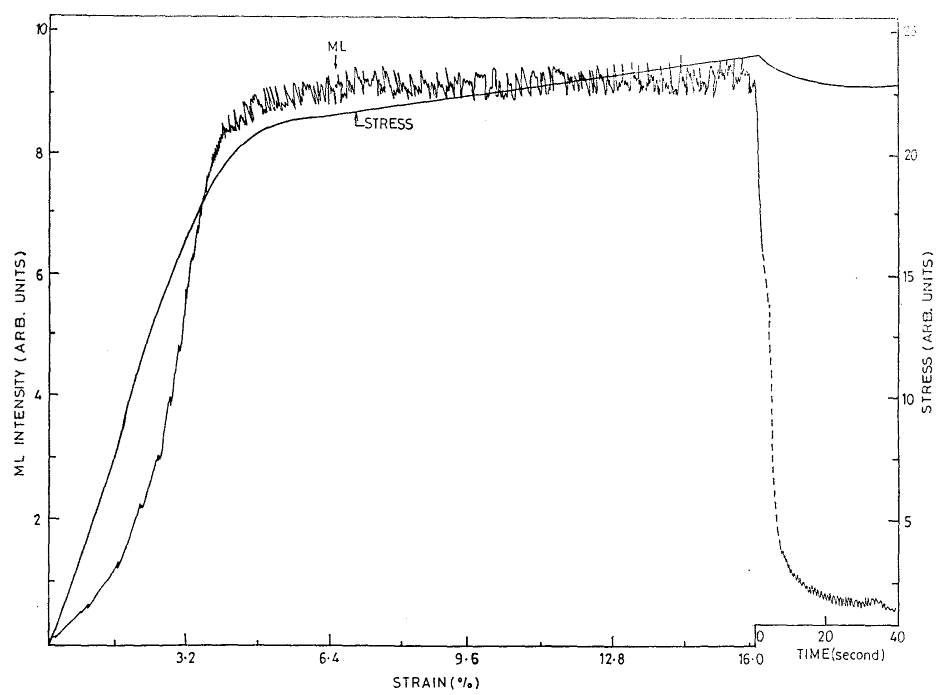


**Fig. 1- ML versus strain and stress versus strain curves of a $\gamma$ -irradiated KCl crystal (dimension =** $5\times5\times5$ mm$^3$ $n_F \approx 10^{17}$ cm$^{-2}$, $\dot{\varepsilon} = 10^{-14}$ sec$^{-1}$)

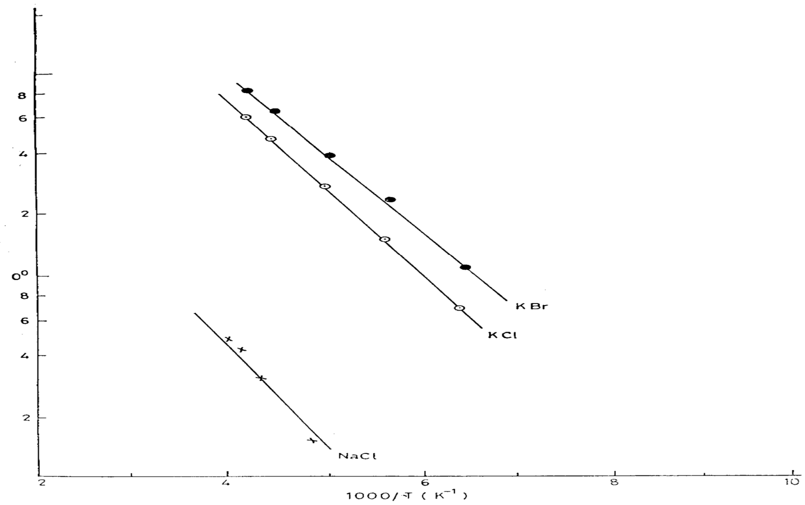


**Fig. 2 – Plot of log (I) versus log** $(\dot{\varepsilon})$ **(dimension =** $5 \times 5 \times 5\ mm^3$ $N_F \approx 10^{17} cm^{-3}$

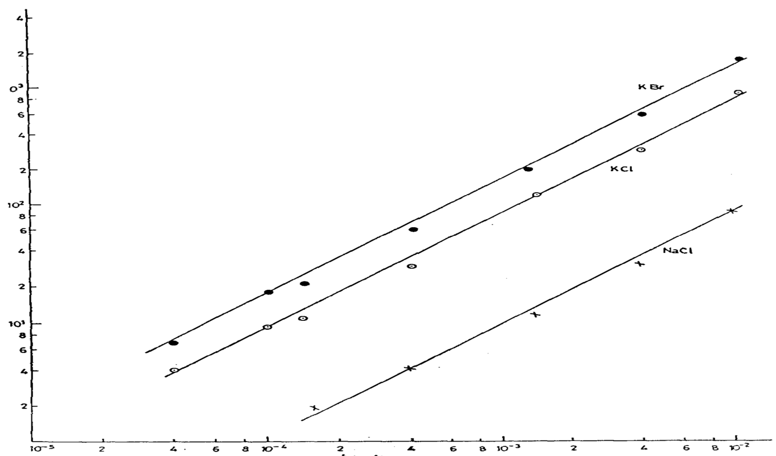


**Fig. 3 – Plot of log ($I_s$) versus 1000/T for $\gamma$ -irradiated KCl, KBr and NaCl crystals**
**($n_F \approx 10^{17} cm^{-3}$, $\dot{\varepsilon} = 10^{-4} sec^{-1}$).**

## EXPERIMENTAL SUPPORT

Fig.1 shows that during the deformation of a $\gamma$ -irradiated KCl crystal at a strain rate of $10^{-4} s^{-1}$, initially the ML intensity increases with strain and then it attains a saturation value after a particular strain. When the deformation is stopped, it is seen that the ML intensity decays, and disappears beyond a particular time. The

initially rise and attainment of saturation are predicted by the proposed dislocation model.

Fig.2 shows that for a given value of $n_F$ and $\dot{\varepsilon}$, the plot of log($I_s$) versus 1/T is a straight line with a negative slope. Such result is expected on the basis of proposed theory (eq. 9). The value of activation energy ($E_a$) determined from the slope of $\log(I_s)$ versus 1/T is found to be 0.07, 0.075, and 0.08eV for KCl, KBr and NaCl crystals, respectively. This result shows that the activation process is involved in the occurrence of ML.

Fig. 3 shows the plot of log ($I_s$) versus log ($\dot{\varepsilon}$). It is seen that this plot a straight line with a slop nearly equal to one. In other words, the ML intensity is linear with the strain rate of the crystals. Such prediction is made by the proposed model.

## CONCLUSIONS

The important conclusions are drawn from the present investigation are as given below:

(1) A theoretical approach based on the transfer of electrons from F-centres to the dislocation band during the mechanical interaction of moving dislocations with F-centres, is made which is successful in explaining several paramenters of the ML in coloured alkali halide crystals.

(2) In coloured alkali halide crystals initially increase of ML intensity with deformation then attainment of a saturation value, linear dependence of ML intensity on the strain rate.

(3) In coloured alkali halide crystals the decay of ML intensity and temperature dependence Ml intensity is also explained.

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